A Hybrid Network Platform for Collaborative Applications

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ABSTRACT

IP Multicast is the most efficient way of distributing real-time content to a group of users with minimum delay. On the other hand, there are many networks that do not let multicast traffic in or out. This has made IP multicast unreliable. Peer to peer networks are used to provide reliable service over unreliable networks. In this paper we propose a peer-to-peer network which serves as an overlay network over a set of Multicast Reflectors, each of which serves a multicast isolated network. We study the effects of such a P2P system on the network administrators and edge routers of multicast isolated networks. We show that the parameters of the P2P system could be chosen such that the system approaches equilibrium.

Keywords

IP Multicast, Peer-to-Peer Networks, Overlay Networks, Incentive based systems, Collaborative Applications.

1. INTRODUCTION

Content delivery to a group of users has been the focus of research for many years. There are several approaches to group content delivery including: IP multicast, application layer multicast and fair exchange p2p networks such as bittorrent. IP multicast was the first effort to provide group communication services. Deployment of IP multicast in the internet is still behind expectations and therefore other approaches are developed to provide reliable group communication services.

1.1 IP Multicast

Today many routers in the Internet are not multicast enabled. There are both marketing and technical reasons [8], [9]:

- Many protocols such as monitoring and congestion control protocols are not yet fully addressed and finalized.
- Multicast breaks the traditional pricing model where the sender pays for his local bandwidth consumption (up to the first router), since in the case of multicast the bandwidth usage gets multiplied by a number greater than or equal to one at each intermediate router.
- The "egg and chicken" problem: There are no good applications (no customer demand) operating on top of IP multicast. On the other hand a stable IP multicast platform is not in place to develop and deploy a good multicast application (to attract customers).

IP multicast's lack of monitoring and congestion control protocols and the pricing problem have turned IP multicast into an error prone and problematic protocol. Event though many of these issues have been resolved and IP multicast can be deployed as a robust and stable service, because of the "egg and chicken" problem and it's bad reputation, Internet service providers and in general network administrators tend to have this service disabled.

1.2 Alternatives to IP multicast

Many alternatives to IP multicast have been developed to address its problems and provide group communication services.

1.2.1 Unicast/Multicast Reflector

In this solution if one or more routers between the multicast source and a host are multicast disabled, the host contacts a reflector through unicast. The reflector receives the desired multicast traffic and tunnels that traffic to the host through a unicast tunnel. UMTP [11] and Mtunnel [12] are examples of such an effort. These examples consider at most two reflectors, one on the multicast disabled host side and another on the multicast source side.

This solution overcomes the "egg and chicken" problem but introduces another class of marketing problems. The reflector is paying a high price for replicating the content for each multicast disabled host. On the other hand if the reflector becomes the main distributor for a wide range of multicast disabled hosts, content delivery is no more efficient. This solution although not solving all the technical and marketing problems, it's a practical way of enabling IP multicast.

1.2.2 Application level multicast

This solution solves some of the marketing and technical problems by relying on end systems [1]. In this approach the group of users interested in the same content form an overlay network. This overlay network emulates IP multicast by assigning some users to be routers and others to be leaves. This takes the pricing problem to the user level where it no more relies on the network infrastructure and service providers.

1.2.3 Fair exchange in P2P networks: Bittorrent

Bittorrent like solutions rely on distributing chunks of data to different peers and let them distribute it among themselves. Although this is a great solution for offline file distribution, it's clear that due to the huge delay and receiving chunks of data out of order, it's not a solution to real time applications such as Internet TV.

2. HYBRID SOLUTION TO MULTICAST

Internet multicast connectivity is the result of each and every router's decision about Enabling/Disabling multicast traffic on different network interfaces. ISPs have been very fortunate due to the "egg and chicken" problem. Although ISPs are selling high bandwidth Internet connections over DSL and Cable, there are no good bandwidth consuming applications, and the bandwidth they are paying for is not utilized. Application layer multicast is not scalable to large scale media distribution applications. Application layer multicast can not implement popular applications such as Internet TV because they are used in large scale. Thus application layer multicast is unable to take advantage of the bandwidth available to users. On the other hand ISPs try to lower their local and up-link bandwidth to lower their usage and bandwidth costs. In reality there is an optimum point of multicast connectivity which both users and ISPs are satisfied. Unfortunately none of the existing group communication protocols let the routers slide to the optimum point of multicast connectivity. In other words, in the game theoretic context, there exists an equilibrium point where the profit of both users and ISPs is maximized. In this game players are routers and decisions are made by ISPs to either disable or enable multicast traffic on routers.

Here we declare the need for a group communication protocol which can take advantage of pure IP multicast when available and application layer multicast where IP multicast is not available. We call such a tool a hybrid solution for group communication protocol. With such a tool, the routers can make the decision for their users to use IP multicast versus application level multicast. In other words, given such a tool the level of multicast connectivity in the Internet will be determined by rational users (routers). A multicast island is a set of connected routers which multicast is enabled between them but no other router is connected to these routers via multicast. This hybrid solution will let rational users (routers) determine the diameter of multicast islands in the internet. Figure 1 visualizes the role of this tool and its possible evolution.

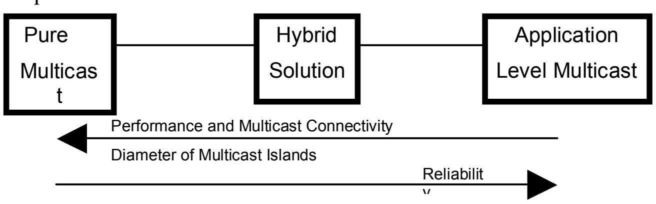

Figure 1 Role of the Hybrid Solution

Application level multicast and pure IP multicast are two extremes to this hybrid solution. On one extreme there is high performance, high multicast connectivity and there is only one multicast island with diameter of the Internet. On the other extreme there is high reliability with multicast islands as many as the number of nodes in the internet and a diameter of zero. The hybrid solution will let this continuous variables be adjusted by rational users (routes) to maximize their profit. Given such a tool we have a model to investigate how different group communication protocols behave with respect to each other and where we will stand in terms of group communication protocols in the future.

Yoid [11] is one of the proposed group communication protocols which claims to use IP multicast where available and application level multicast where IP multicast is not available. Despite implementation and deployment issues for Yoid, we use this protocol as an existing protocol which claims to behave as what we call a Hybrid Solution.

3. ECONOMICS OF MULTICAST

Although pure IP multicast and application level multicast have their own economics and games we look into a more abstract game theoretic aspect of this issue which is far more complex. The IP multicast game has a dominating strategy where all routers disable IP multicast, and we can easily see this in today's level of multicast connectivity. The economics of application level multicast investigates the incentives of peers to contribute to the P2P network. The hybrid solution brings a new dimension to the multicast games, a tool which can change the level of multicast connectivity in the Internet. Since this is a very complex game and has many deciding factors we need to simplify the game and solve it for simple topologies. This gives us some insight to the dynamics of such a system. We will use these insights to study the dynamics of the system in a more general topology and declare our final results.

3.1 The Multicast Game

The multicast game is defined as a set of players, available strategies and a cost function. The cost function assigns a cost to each player given all player strategies. The game is defined as follows:

- Players: Routers managed by ISPs.
- Strategies: Enabling multicast traffic on internal network interface but disabling on external interface (DEI[1]), enabling multicast on all network interfaces (EAI[2]) and disabling multicast traffic on all network interfaces (DAI[3]) (The case where internal network interface is disabled but external network interface is enabled is eliminated, since this is not a popular scenario).
- Cost Function: The cost function is defined as router's incoming and outgoing packets.

3.2 Basic Model Analysis

We consider a basic model where only two routers are involved. We investigate the effects of routers decision on other routers in terms of their cost function. We assume a perfect application layer multicast and IP multicast combination. In our model, once multicast content reaches a peer in a multicast island, that peer distributes the content in the multicast island. In other words contents enter multicast islands only once. We refer to the distributor peer in a multicast island as a reflector.

3.2.1 Star Topology

For simplicity we first consider a star topology on both routers. This is a simple model for two ISPs with DSL or dialup users (See Figure 2). In this model P1 has m members of a group G and P2 has n members of the same group.

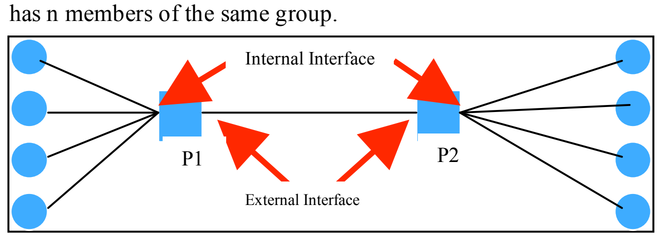

Figure 2 - Two routers star topology

We investigate the cost function for three set of strategies and analyse the game. We let the sender be on P1 side without loss of generality, since the topology is symmetric.

1. P1 and P2 both play EAI: The sender sends the data to P1. P1 forwards the data to other users and also to P2. Therefore P1 has 1 incoming packet and m outgoing packets. The same thing is true for P2: 1 incoming packet and n outgoing packet (See Figure 3).

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[1] Disable External Interfaces

[2] Enable All Interfaces

[3] Disable All Interfaces

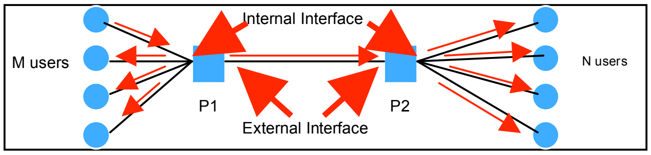

Figure 3 - P1 and P2 play EAI

2. P1 plays DEI and P2 plays EAI: In this scenario the sender sends a packet to P1 which forwards the packet to other users and then sends it to a peer in P2 users (the reflector). The reflector in P2 sends the packet back to P2 which forwards the packet to other P2 users. Given these strategies, P1 has 2 incoming packets and m outgoing packets. P2 also has 2 incoming packets and n outgoing packets (See Figure 4).

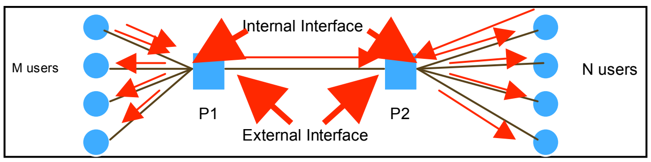

Figure 4 - P1 plays DEI, P2 plays EAI

3. P1 plays DAI and P2 plays EAI: Given these set of strategies the sender needs to send the packet to all P1 users and then send another packet to the reflector on P2 side. The reflector on P2 side will then distribute the packet to other users through IP multicast. In this case P1 has m incoming packets and m outgoing packets. P2 has 2 incoming packets and n outgoing packets.

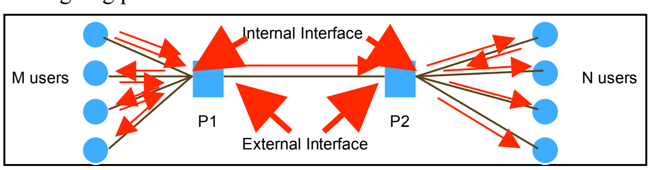

Figure 5 - P1 plays DAI, P2 plays EAI

4. P1 and P2 both play DEI: In this set of strategies using the same reasoning from the previous case, P1 has 2 incoming and m outgoing packets. P2 has 2 incoming and n outgoing packets.
5. P1 plays DEI and P2 plays DAI: In this scenario since after P2 disables the external interface the external interface of P1 is no more important. Therefore enabling or disabling the external interface of P1 does not change the cost for either P1 or P2. Using the symmetry of the topology, this scenario has similar results as in case number 3. P1 has 2 incoming packets and m outgoing packets. P2 has n incoming packets and n outgoing packets.
6. P1 and P2 both play DAI: Using the same reasoning from previous cases P1 has m incoming packets and m outgoing packets. P2 has n incoming packets and n outgoing packets.

The results of all possible cases are displayed in Table 1.

Table 1 - Cost function for all strategy combinations - The first row in each cell is P1's cost and the second row is P2's cost. Each cost value contains the incoming packets (first element) and outgoing packets (second element).

P2 \ P1	DAI	DEI	EAI
DAI	(M,M) (N,N)	(2,M) (N,N)	(2,M) (N,N)
DEI	(M,M) (2,N)	(2,M) (2,N)	(2,M) (2,N)
EAI	(M,M) (2,N)	(2,M) (2,N)	(1,M) (1,N)

Given the set of players and the cost function, there exists a weakly dominating strategy. That is where both P1 and P2 chose EAI strategy. Given this we clearly observe that enabling multicast on all interfaces is the best strategy. Unfortunately this is not what is happening in the real world scenarios.

How ever there is another interpretation of such a cost function. That is, the cost for a router in the Multicast World is the number outgoing packets minus the number of incoming packets. In other words this number presents the number of packets the router is originating by forwarding these packets to multiple destinations. This is what the router is spending out of its own pocket and is less desirable (Table 2).

Table 2 – Differential cost function for all strategy combinations (Number of outgoing packets minus number of incoming packets)

P2 \ P1	DAI	DEI	EAI
DAI	0 0	M-2 0	M-2 0
DEI	0 N-2	M-2 N-2	M-2 N-2
EAI	0 N-2	M-2 N-2	M-1 N-1

We clearly see that disabling multicast traffic on all interfaces is a strongly dominating strategy for both players. This cost function gives more insight into the dynamics of the system and the reason where many ISPs disable multicast in whole. A more comprehensive analysis is provided as we develop a more comprehensive model.

3.2.2 LAN Topology

This is a similar model where P1 has m users on a LAN and P2 has n users on another LAN, all in the same multicast group. The main deference in this model is the fact that disabling multicast on internal interface doesn't change anything, since communication on a LAN is independent of the router. Therefore in this case there are only two strategies.

1. Enable Multicast (EM): Enabling on external interface (EAI).
2. Disable Multicast (DM): Disabling multicast on external interface (DEI or DAI).

The topology of this model is shown in Figure 6 and the cost function is displayed in Table 3.

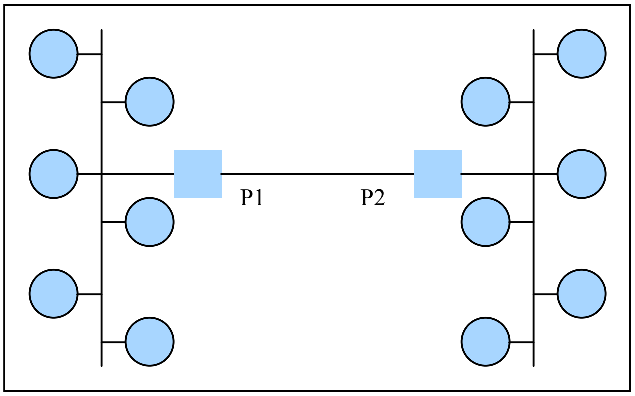

Figure 6 - LAN Topology

Table 3 - Cost function - First element of each cost is the routing cost and the second element is the local link cost.

P2 \ P1		MC Disabled		MC Enabled
		DAI	DEI	EAI
MC Disabled	DAI	(1,2) (1,2)		(1,2) (1,2)
	DEI			
MC Enabled	EAI	(1,2) (1,2)		(1,1) (1,1)

Enabling multicast for both routers is a weakly dominating strategy. But since the only difference between costs is the local link cost, it's doesn't make a huge difference in cost and maybe other factors play a more important role in enabling multicast.

Looking at the differential cost function table (Table 4), there is clearly no difference between enabling and disabling multicast in this case.

Table 4 - Differential cost function (Number of outgoing packets minus number of incoming packets)

P2 \ P1		MC Disabled		MC Enabled
		DAI	DEI	EAI
MC Disabled	DAI	0 0		0 0
	DEI			
MC Enabled	EAI	0 0		0 0

We conclude that in a game with such a model routers should be a little biased toward enabling multicast, although there is not enough incentives to do so. Moreover there are other factors that might discourage routers from enabling multicast. These factors are studied later in this paper.

3.3 Multiple Groups

Previous discussions are based on a single multicast group. Multiple group support is essential to provide more insight into the dynamics of the system.

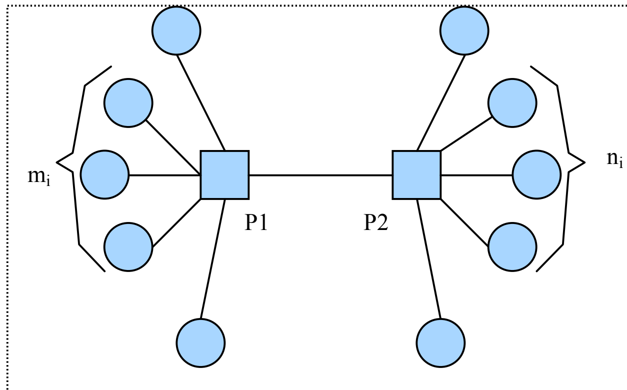

Figure 7 - Star toplogy with multiple groups

In this setup there are M multicast groups on side P1 each have m_i members and N multicast groups on side P2 each have n_i members. Total number of users on side P1 and P2 are $\sum_{i=1}^{M} m_i$ and $\sum_{i=1}^{N} n_i$ respectively. Given these assumptions the cost function is given in Table 5. We clearly see the same results where enabling multicast on all interfaces is a weakly dominating strategy. The differential cost function table is given in Table 6.

Table 5 - Cost function for multiple groups

P2 \ P1	DAI	DEI	EAI
DAI	$(\sum_{i=1}^{M} m_i , \sum_{i=1}^{M} m_i)$ $(\sum_{i=1}^{N} n_i , \sum_{i=1}^{N} n_i)$	$(2M, \sum_{i=1}^{M} m_i)$ $(\sum_{i=1}^{N} n_i , \sum_{i=1}^{N} n_i)$	$(2M, \sum_{i=1}^{M} m_i)$ $(\sum_{i=1}^{N} n_i , \sum_{i=1}^{N} n_i)$
DEI	$(\sum_{i=1}^{M} m_i , \sum_{i=1}^{M} m_i)$ $(2N, \sum_{i=1}^{N} n_i)$	$(2M, \sum_{i=1}^{M} m_i)$ $(2N, \sum_{i=1}^{N} n_i)$	$(2M, \sum_{i=1}^{M} m_i)$ $(2N, \sum_{i=1}^{N} n_i)$
EAI	$(\sum_{i=1}^{M} m_i , \sum_{i=1}^{M} m_i)$ $(2N, \sum_{i=1}^{N} n_i)$	$(2M, \sum_{i=1}^{M} m_i)$ $(2N, \sum_{i=1}^{N} n_i)$	$(M, \sum_{i=1}^{M} m_i)$ $(N, \sum_{i=1}^{N} n_i)$

Table 6 - Differential cost function for multiple groups

P2 \ P1	DAI	DEI	EAI
DAI	0 0	$\sum_{i=1}^{M} m_i$ - 2M 0	$\sum_{i=1}^{M} m_i$ - 2M 0
DEI	0 $\sum_{i=1}^{N} n_i$ -2N	$\sum_{i=1}^{M} m_i$ - 2M $\sum_{i=1}^{N} n_i$ -2N	$\sum_{i=1}^{M} m_i$ - 2M $\sum_{i=1}^{N} n_i$ -2N
EAI	0 $\sum_{i=1}^{N} n_i$ -2N	$\sum_{i=1}^{M} m_i$ - 2M $\sum_{i=1}^{N} n_i$ -2N	$\sum_{i=1}^{M} m_i$ - M $\sum_{i=1}^{N} n_i$ -N

Disabling multicast traffic on both interfaces is a strongly dominating strategy given the differential cost function.

4. CONCLUSION

In this paper we investigated the dynamics of the multicast world from a new perspective. The following are the main results of this paper.

- ISPs are more concerned about doing more than they are paid for, rather than doing more work. In other words, ISPs are doing more work by disabling multicast, but they are not doing extra work (unpaid). If ISPs can afford to do some unpaid work, they will end up doing less work.
- Disabling multicast on internal interfaces only changes that router's cost and no other ones.
- A router does not care about other routers multicast connectivity unless multicast traffic is enabled on its external interface.

5. FUTURE WORK

The future work will be applying the same methods to a more comprehensive topology and finding the optimal diameter for multicast islands and whether the social optimum is reachable by independent decisions of rational users.

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